

**Optimization of Mud Hammer Drilling Performance –
A Program to Benchmark the Viability of
Advanced Mud Hammer Drilling**

Quarterly Progress Report

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ABSTRACT

This document details the progress to date on the OPTIMIZATION OF MUD HAMMER DRILLING PERFORMANCE – A PROGRAM TO BENCHMARK THE VIABILITY OF ADVANCED MUD HAMMER DRILLING contract for the quarter starting October 2002 through December 2002.

Even though we are awaiting the optimization portion of the testing program, accomplishments included the following:

- Smith International participated in the DOE Mud Hammer program through full scale benchmarking testing during the week of 4 November 2003.
- TerraTek acknowledges Smith International, BP America, PDVSA, and ConocoPhillips for cost-sharing the Smith benchmarking tests allowing extension of the contract to add to the benchmarking testing program.
- Following the benchmark testing of the Smith International hammer, representatives from DOE/NETL, TerraTek, Smith International and PDVSA met at TerraTek in Salt Lake City to review observations, performance and views on the optimization step for 2003.
- The December 2002 issue of Journal of Petroleum Technology (Society of Petroleum Engineers) highlighted the DOE fluid hammer testing program and reviewed last years paper on the benchmark performance of the SDS Digger and Novatek hammers.
- TerraTek's Sid Green presented a technical review for DOE / NETL personnel in Morgantown on 'Impact Rock Breakage' and its importance on improving fluid hammer performance. Much discussion has taken place on the issues surrounding mud hammer performance at depth conditions.

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INTRODUCTION

The focus of the Introduction for this quarter will be on the recently completed benchmark testing of the Smith International fluid hammer under conditions established by the program last year.

Following deployment of the Smith hammer offshore Vietnam during August and September of 2002, the hammer was stripped, inspected and readied for DOE testing at TerraTek. The hammer is a nominal 7" size and used a standard 8-1/2" air hammer bit shown in the photograph below.



EXECUTIVE SUMMARY

Background

On January 9th of 2001, details of the Mud Hammer Drilling Performance Testing Project were presented at a “kick off” meeting held in Morgantown. Industry support is high and the importance to the drilling industry, as the business challenge of “hard rock drilling”, was presented by John Shaughnessy of BP Amoco. The Industry Partners for this program are SDS Digger Tools, Novatek, BP Amoco, and ExxonMobil. A test program was formulated and prepared for presentation at a meeting of the Industry Advisory Board in Houston on the 8th of February. The meeting was held and the DOE approved a test program was after thorough discussion.

DOE’s National Energy Technology Laboratory highlighted the Mud Hammer Project at an exhibit at the Offshore Technology Conference April 30 through May 3, 2001. TerraTek assisted NETL personnel with presentation materials appropriate for the project and a demonstration sample of ‘hard rock’ drilled in TerraTek’s wellbore simulator.

TerraTek completed 13 drilling tests by beginning July in Carthage Marble and hard Crab Orchard Sandstone with the SDS Digger Tool, Novatek tool, and a conventional rock bit. Overall the hammers are functioned properly at ‘borehole’ pressures up to 3,000 psi with weighted water based mud. Clearly the Department of Energy goals to determine hammer ***benchmark rates of penetration*** and ***ability to function at depth*** are being met. Additionally data on drilling intervals and rates of penetration specific to flow rates, pressure drops, rotary speed, and weights-on-bit have been given to the Industry Partners for detailed analysis. SDS and Novatek have gained considerable experience on the operation of their tools at simulated depth conditions. Some optimization has already started and has been identified as a result of these first tests.

TerraTek has completed analysis of drilling performance (rates of penetration, hydraulics, etc.) for the Phase One testing which was completed at the beginning of July. TerraTek also convened jointly with the Industry Advisory Board for this project and DOE/NETL a ‘lessons learned meeting’ to transfer technology vital for the next series of performance tests. Both hammer suppliers benefited from the testing program and are committed to pursue equipment improvements and ‘optimization’ in accordance with the scope of work.

PDVSA joined the advisory board to this DOE mud hammer project end 2001 and has formally committed funds (cost sharing) for the upcoming effort in testing at TerraTek. Additionally, TerraTek, DOE, and BP America (one of the industry contributing partners) has completed a publication entitled “World’s First Benchmarking of Drilling Mud Hammer Performance at Depth Conditions”.

In accordance to Task 7.0 (D. #2 Technical Publications) TerraTek, NETL, and the Industry Contributors successfully presented a paper detailing Phase 1 testing results at

the February 2002 IADC/SPE Drilling Conference, a prestigious venue for presenting DOE and private sector drilling technology advances. The full reference is as follows:

IADC/SPE 74540 "World's First Benchmarking of Drilling Mud Hammer Performance at Depth Conditions" authored by Gordon A. Tibbitts, TerraTek; Roy C. Long, US Department of Energy, Brian E. Miller, BP America, Inc.; Arnis Judzis, TerraTek; and Alan D. Black, TerraTek. Gordon Tibbitts, TerraTek, will presented the well-attended paper in February of 2002. The full text of the Mud Hammer paper was included in the last quarterly report.

The Phase 2 project planning meeting (Task 6) was held at ExxonMobil's Houston Greenspoint offices on February 22, 2002. In attendance were representatives from TerraTek, DOE, BP, ExxonMobil, PDVSA, Novatek, and SDS Digger Tools. PDVSA has joined the advisory board to this DOE mud hammer project. PDVSA's commitment of cash and in-kind contributions were reported during the last quarter. Strong Industry support remains for the DOE project. Both Andergauge and Smith Tools have expressed an interest in participating in the 'optimization' phase of the program. The potential for increased testing with additional Industry cash support was discussed at the planning meeting in February 2002.

Presentation material was provided to the DOE/NETL project manager (Dr. John Rogers) for the DOE exhibit at the 2002 Offshore Technology Conference. Two meeting at Smith International and one at Andergauge in Houston were held to investigate their interest in joining the Mud Hammer Performance study.

SDS Digger Tools (Task 3 Benchmarking participant) apparently has not negotiated a commercial deal with Halliburton on the supply of fluid hammers to the oil and gas business. TerraTek is awaiting progress by Novatek (a DOE contractor) on the redesign and development of their next hammer tool. Their delay will require an extension to TerraTek's contracted program. Smith International has sufficient interest in the program to start engineering and chroming of collars for testing at TerraTek.

Shell's Brian Tarr has agreed to join the Industry Advisory Group for the DOE project. The addition of Brian Tarr is welcomed as he has numerous years of experience with the Novatek tool and was involved in the early tests in Europe while with Mobil Oil. Finally, Conoco's field trial of the Smith fluid hammer for an application in Vietnam was organized and has contributed to the increased interest in their tool.

Smith International agreed to participate in the DOE Mud Hammer program mid 2002 and chromed collars for upcoming benchmark tests at TerraTek, scheduled for 4Q 2002. ConocoPhillips had a field trial of the Smith fluid hammer offshore Vietnam. The hammer functioned properly, though the well encountered hole conditions and reaming problems. ConocoPhillips plan another field trial as a result.

DOE/NETL extended the contract for the fluid hammer program to allow Novatek to 'optimize' their much delayed tool to 2003 and to allow Smith International to add 'benchmarking' tests in light of SDS Digger Tools' current financial inability to participate. ConocoPhillips joined the Industry Advisors for the mud hammer program

and TerraTek acknowledges Smith International, BP America, PDVSA, and ConocoPhillips for cost-sharing the Smith benchmarking tests allowing extension of the contract to complete the optimizations tests.

Current

During 4Q 2002, Smith International participated in the DOE Mud Hammer program through full scale benchmarking testing (5 tests) during the week of 4 November 2003. TerraTek acknowledges Smith International, BP America, PDVSA, and ConocoPhillips for cost-sharing the Smith benchmarking tests allowing extension of the contract to add to the benchmarking testing program. Following the benchmark testing of the Smith International hammer, representatives from DOE/NETL, TerraTek, Smith International and PDVSA met at TerraTek in Salt Lake City to review observations, performance and views on the optimization steps for 2003. The December 2002 issue of Journal of Petroleum Technology (Society of Petroleum Engineers) highlighted the DOE fluid hammer testing program and reviewed last years paper on the benchmark performance of the SDS Digger and Novatek hammers. And finally, TerraTek's Sid Green presented a technical review for DOE / NETL personnel in Morgantown on 'Impact Rock Breakage' and its importance on improving fluid hammer performance. Much discussion has taken place on the issues surrounding mud hammer performance at depth conditions.

EXPERIMENTAL

Experimental work for 'Benchmark' testing has been completed with the introduction of the Smith International hammer tests during the week of 4 November 2002.

The following test matrix was followed (13 tests were previously done):

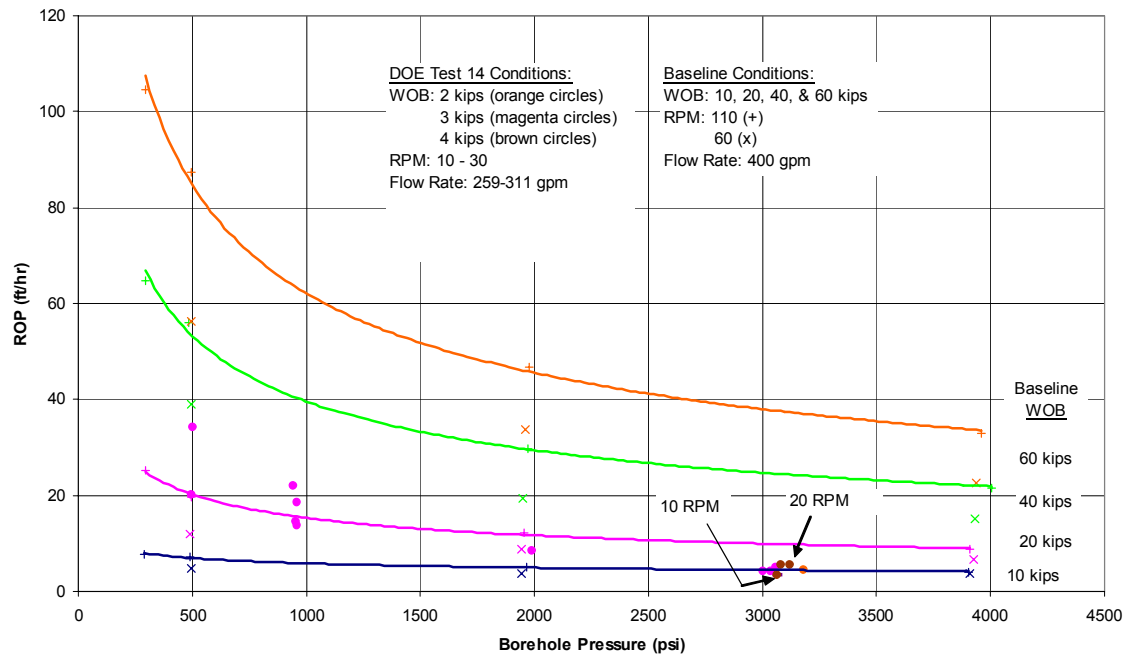
DOE Number	Hammer/Bit	Rock	Mud Density, ppg
13	3 cone IADC Code 537	Carthage	9 ppg brine
14	Smith	Carthage	9 ppg brine
15	Smith	Carthage	10 ppg water-based
16	Smith	Crab Orchard	10 ppg water-based
17	Smith	Carthage	15 ppg water-based

From previous testing, the comparison to 'conventional drilling' is available for 10 and 15 ppg fluids. Industry input at the February '02 planning meeting (particularly BP, PDVSA) prompted plans to use a lighter weight brine as extra data points.

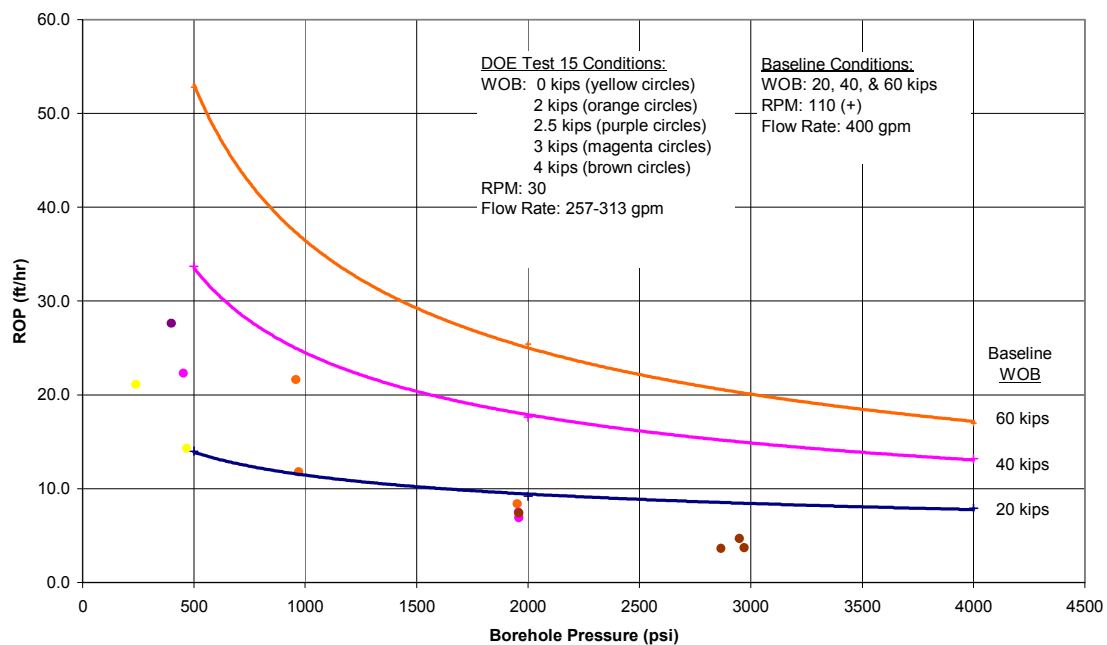
RESULTS AND DISCUSSION

This section of the report presents performance results of the Smith Hammer during the three month time period.

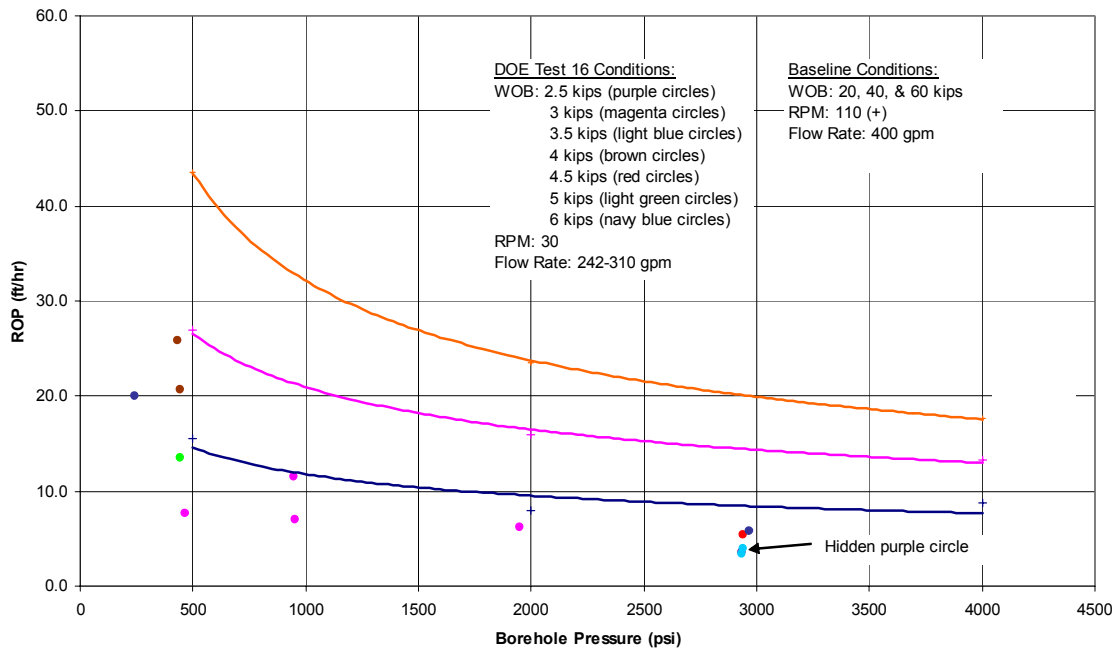
**DOE Test 14 with Smith Hammer Compared with 8 1/2" Reed HPSM Baseline Bit
for 9.0 ppg NaCl Brine and Carthage Marble**



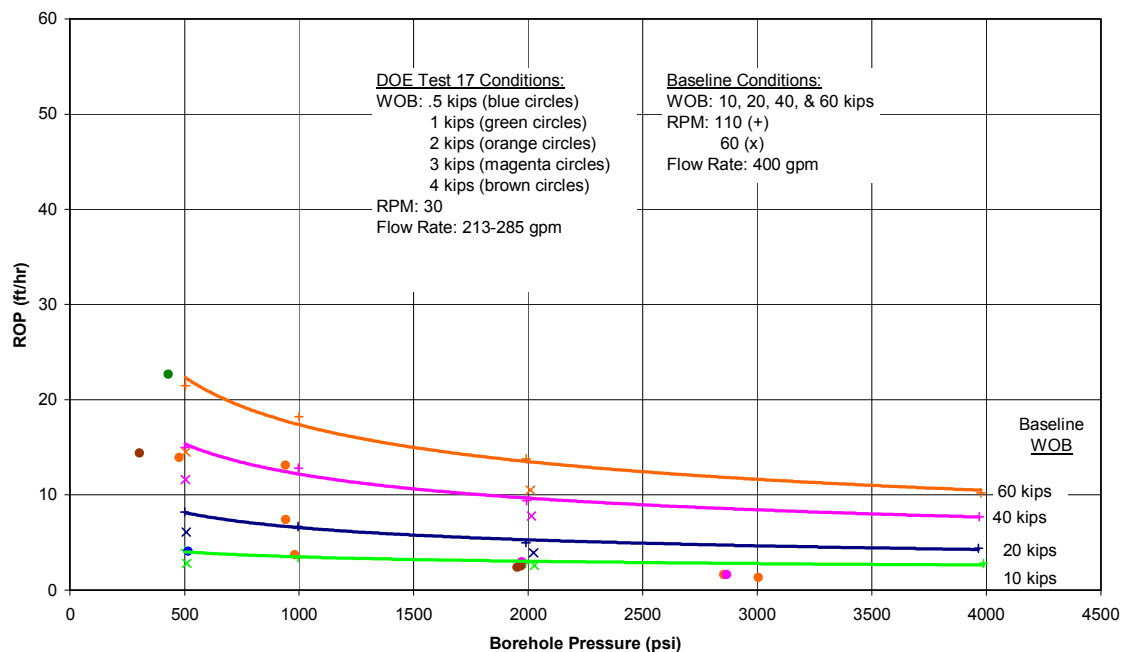
**DOE Test 15 with Smith Hammer Compared with 8 1/2" Reed HPSM Baseline Bit
for 10 ppg Water-Base Mud and Carthage Marble**



DOE Test 16 with Smith Hammer Compared with 8 1/2" Reed HPSM Baseline Bit for 10 ppg Water-Base Mud and Crab Orchard Sandstone

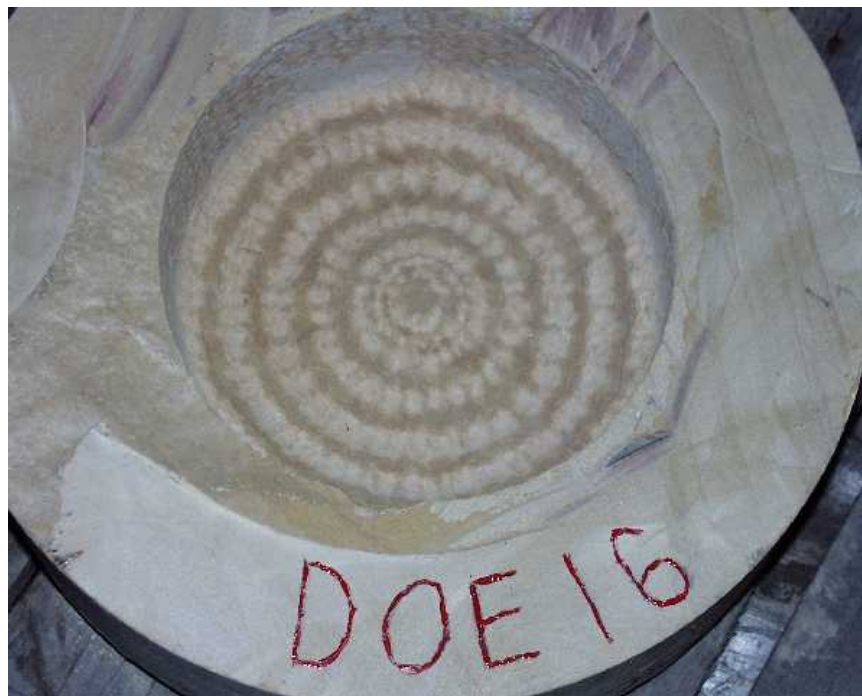


DOE Test 17 with Smith Hammer Compared with 8 1/2" Reed HPSM Baseline Bit for 15 ppg Water-Base Mud and Carthage Marble



Bottomhole patterns were also photographed;







Lesson Learned Meeting Summary November 7, 2002

Attendees; John Rogers (DOE / NETL), Lance Underwood and Shantanu Swadi (Smith International), Alejandro Lagreca and Delcio de Santana (PDVSA), and Arnis Judzis (TerraTek). Regrets from Rich Reiley (BP) and Gary Collins (ConocoPhillips).

Discussion;

Lance Underwood (Smith) – Some field experience [data] better than observed at TerraTek; performance did not beat 3 cone bit especially with high borehole pressures. 80% of their forecasted market is at 10 ppg or less. Smith views energy input and bit design important for optimization. Check into higher rate data collection for optimization tests. Smith potential markets for mud hammer – Brazil, Travis Peak and Cotton Valley sandstones, cherts in W. Texas, carbonates various locations. Lance is also interested in rock destruction by looking at impact testing of single cutters, etc. Need to quantify effects and energy requirements at high borehole pressures among other things.

Shantanu Swadi (Smith) – Also views energy input as being crucial.

Alejandro Lagreca (PDVSA) – Need to understand fundamental relationships such as energy input. ROP can be studied . . . will have to also look at longevity. 9 or 10 ppg fluid seen as biggest current use for hammers.

John Rogers (NETL) – Parameters such as mud weight can be suggested by operators and service companies. 15 ppg mud weight could be representative of Tuscaloosa or deep Anadarko. DOE's aim is to improve gas productivity in the domestic market and fluid hammers should make a difference. What do we need to change for upcoming optimization tests? . . . energy level, hammer/bit system, etc. Make ROP good and reliable.

December 2002 Issue 'Journal of Petroleum Technology'



Mud-Hammer Drilling Performance

This article, written by Assistant Technology Editor Karen Bybee, contains highlights of paper SPE 74540, "World's First Benchmarking of Drilling Mud-Hammer Performance at Depth Conditions," by Gordon A. Tibbits, TerraTek; Roy C. Long, SPE, U.S. Dept. of Energy; Brian E. Miller, SPE, BP; and Arnis Judzis, SPE, and Alan D. Black, SPE, TerraTek, originally presented at the 2002 IADC/SPE Drilling Conference, Dallas, 26-28 February.

Operators continue to look for ways to improve hard-rock drilling performance. A consortium of Dept. of Energy (DOE), operator, and industry participants assembled an effort to test and optimize mud-driven fluid hammers as an emerging technology that shows promise to increase penetration rates in hard rock. The full-length paper details the results of full-scale testing of two 7 3/4-in.-diameter mud hammers with 8 1/2-in. hammer bits and compares their performance with a conventional tricone bit.

Introduction

The majority of drilling-related costs are incurred drilling harder rock. Improved rate of penetration (ROP) in hard rock has the potential to reduce overall well costs. Estimated costs to drill hard rock in the U.S. is U.S. \$1,200 million. Potential savings of U.S. \$200 million to \$600 million are possible if ROP in hard rock is doubled with reasonable bit life. Mud-hammer development has been going on for some time, but performance and endurance have not been tested adequately for mud hammers to be a viable commercial tool in deep drilling applications. Hammer performance had been sketchy at best, and mud hammers are reported to have performance problems at high borehole pressures and in muds containing high solids percentages. Full-scale testing under simulated drilling conditions offered an economical alternative to high-day-rate field testing as well as a clear performance comparison of different power levels, rotary speeds, weight on bit (WOB), bit types, mud densities, and rock types.

Background

The DOE implements its Office of Fossil Energy upstream natural-gas technology development program by cost-shared research projects. These projects are initiated and managed by DOE's Natl. Energy Technology Laboratory (NETL). In response to the Energy Information Admin. forecast that gas consumption will increase 60% by 2020, NETL is cost-sharing various technology-development projects to enhance deep-gas development. NETL's focus on mud hammers is a direct result of its attempt to reduce drilling costs and make deep-gas exploration economics more attractive to industry. The mud hammer was considered to be a technology with potential to reduce deep-gas drilling costs because of demonstrated capabilities of existing air and water hammers in hard-rock drilling applications and ease of incorporating mud hammers into existing drilling systems.

Operator Needs

For hard and abrasive drilling conditions in deep wells drilled with mud, tricone bits have the highest ROP, but their susceptibility to wear and bearing failure limits their drilling time. In deeper hole sections, where tripping times are longer, thermally stable polycrystalline or natural diamond bits are chief competitors of the tricone bit, especially in smaller hole sizes. Thermally stable polycrystalline and natural diamond bits have a much longer bit life to offset their lower ROP and reduce overall cost per foot compared with tricone bits. Hammer drilling with simple percussion drill bits has proved to be an economical alternative for a range of hard-rock drilling applications including drilling with air or clear water as drilling fluid. Air drilling results in the highest ROPs, and air-hammer drilling is a widely used alternative for many air-drilled hole sections. Hammer drilling with percussion bits in clear water is a relatively new alternative that has been limited to relatively shallow holes (i.e., less than 3,000 ft). Because of hammer drilling performance in clear-water applications, operators are interested in learning if these drilling systems can provide an economic alternative in hard-rock drilling applications with weighted muds at deeper hole depths. The controlled drilling tests reported in the full-length paper provide key insights into mud-hammer drilling not available from random field tests.

Test Program

To determine economic viability of hammer drilling with percussion bits in deep hole sections drilled with weighted mud, the test program was designed to explore only the ROP performance of available fluid-driven hammer tools. An advisory board composed of representatives from the DOE/NETL, ExxonMobil, BP, TerraTek, Novatek, SDS Digger Tools, and Pajarito Enterprises directed the test program. Carthage marble was selected to represent a moderately hard limestone. Crab Orchard sandstone was selected to represent hard sandstone. Two water-based muds (WBM), 10.0 and 15.0 lbm/gal, were used for high-solids-content drilling fluids to provide realistic comparisons to field muds used in conventional drilling. Performance of an 8 1/2-in. tricone bit [Intl. Assn. of Drilling Contractors (IADC) 537 tungsten carbide insert bit] was documented in paper SPE 15620, "Roller-Bit Penetration Rate Response as a Function of Rock Properties and Well Depth." The tests described were run using a 10.0-lbm/gal WBM while drilling Carthage marble and Crab Orchard sandstone at various WOB conditions and constant rotary speed. Additional tests were performed with the same bit with 15.0-lbm/gal WBM.

As borehole pressure increases, ROP decreases. The highest borehole pressure was 3,000 psi. Data also were obtained at 2,000, 1,000, and 500 psi. Confining stress and overburden stress were held constant at 4,000 psi and 5,000 psi, respectively. Although the main goal of the program was to examine drilling performance at the 3,000-psi borehole pressure, the lower-borehole-pressure data provided information about the performance transition from low to higher borehole pressure. All mud-hammer and conventional drilling tests were run in a wellbore simulator that can perform drilling experiments with full-scale bits, high flow volumes, and high fluid pressure with a variety of drilling muds and rock samples stressed to in-situ conditions. The laboratory has extensive instrumentation and data collection equipment to measure and record information from drilling experiments. In a typical test, the 15 1/2-in. jacketed rock sample was connected to the top vessel plug that sealed the mud hammer and bit combination. The assembly then was lowered into the wellbore simulator. The upper closure of the wellbore simulator would be inserted and the drillstring made up to the drilling rig. Because the rock samples were relatively strong, confining and overburden stresses were applied to the rock before flowing the pressurized mud into the borehole. When rock stresses and borehole pressure were established, the sample was drilled following a procedure that outlined tool pressure drop, rotary speed, and WOB.

Results

The tricone bit did not perform as well in the 15-lbm/gal WBM as in the 10-lbm/gal WBM. Rotary speed for both mud weights was 110 rev/min, but the data for the 15-lbm/gal WBM contains some data taken at 60 rev/min. Hydraulic horsepower per square inch for the 15-lbm/gal mud was maintained by running different nozzle diameters in the bit at the same flow rate. Results of the tricone bit tests comprise the baseline and comparison data for mud-hammer performance.

SDS Tool Performance. The SDS tool operates (cycles) only after a predetermined weight is applied to the tool. The tool cycles very smoothly. The bypass nozzles were blocked off during these tests, although in field operation they are directed uphole and may be fitted with different diameter nozzles to match drilling rig hydraulic requirements. Fig. 1 shows the impact bit used with the SDS mud hammer. In Carthage marble, ROP performance at 3,000-psi borehole pressure appears to be approximately the same at all pressure drops and rotary speeds. ROP is 2 to 4 ft/hr. WOB was a constant 10,000 lbf.



Fig. 1—Impact bit used with the SDS mud hammer.

Performance was similar in Crab Orchard sandstone with 10-lbm/gal WBM. Performance at various pressure drops and rotary speeds is lower than with a conventional bit, especially at borehole pressures greater than 1,000 psi. ROP was 2 to 4 ft/hr. Similar results were obtained in the two rock types when mud weight was increased to 15 lbm/gal, although ROP was lower in the higher-weight mud system. ROP ranged from 1 to 3 ft/hr. When a more aggressive percussion-type bit was run with the mud hammer, significant improvement was seen at lower borehole pressures, and, in some cases, performance was better than the tricone performance. As the borehole pressure was increased, performance improved moderately. ROP at 3,000-psi borehole pressure ranged from 3 to 7 ft/hr.

Novatek Performance. The Novatek tool operates (cycles) when a minimum amount of fluid is pumped through the tool, and it will cycle with no WOB. As WOB is applied, the tool closes until the anvil is loaded and then transfers the impacts to the cutting structure. When a Novatek N5 mud hammer was run with an IADC 537 tricone bit in 10-lbm/gal mud, the resulting ROPs clustered around the performance of the standard IADC 537 tricone rotary drilling results at its lowest WOB and 110 rev/min. ROP ranged from 4 to 10 ft/hr. Although performance levels for the Novatek tool and the polycrystalline diamond cutter bit (Fig. 2) were in the lower range or below the comparison bit in early tests, a couple of points were observed that showed moderate performance increases over the IADC 537 bit. The performance level of the Novatek tool and polycrystalline diamond cutter bit exceeded that of the rotary-drilled tricone bit in Crab Orchard sandstone and came close to the best-case performance curve when drilling the Carthage marble.



Fig. 2—Novatek bit.

Conclusions

1. New generation mud hammers have the ability to operate in 10- to 15-lbm/gal WBM.
2. There is no advantage in using mud hammers with conventional IADC 537 tricone bits.
3. Drill bits designed to exploit both rotary and impact-applied loads provide better performance used with mud hammers.
4. Performance improvement is significant for the Novatek mud hammer in the transition region between low and high WOB.

***** *End of publication* *****

CONCLUSIONS

- Benchmarking of the Smith International fluid hammer was completed in November 2002.
- Tasks 1, 2, 3, 4, and 5 are completed in the original format, now complete also with respect to Task 3 Smith tool benchmarking during 4Q 2002.
- Task 6 started having concluded a Planning Meeting to determine the test matrix for the next phase of testing. The Industry Advisors will reconvene an additional time prior to formalizing the optimization test matrix.
- Task 7 D2 completed with formal presentation / paper as encouraged by DOE/NETL.

REFERENCES

‘Mud-Hammer Drilling Performance’, Journal of Petroleum Technology, December, 2002, pg 38.